<u>We claim</u>:

1.   A method of determining an optimum bit load per subchannel in a multicarrier

system with forward error correction, comprising:

     computing one or more values of a maximum number of symbol errors that

can be corrected t, and a number of symbols in the information field K to determine

the optimum bit load per subchannel in accordance with the following relationship:

$$1-\left(1-W(s,z,K)\varepsilon_S^{\frac{1}{0.5\cdot sz+1}}\right)^{1/\alpha}$$

$$=\omega\left(b\left(\gamma_{eff},s,z\right)\right)\left(1-2^{-b\left(\gamma_{eff},s,z\right)/2}\right)erfc\left(\sqrt{3\cdot10^{\gamma_{eff}/10}/\left(2^{b\left(\gamma_{eff},s,z\right)+1}-2\right)}\right), \text{ and}$$

$$\times\left[2-\left(1-2^{-b\left(\gamma_{eff},s,z\right)/2}\right)erfc\left(\sqrt{3\cdot10^{\gamma_{eff}/10}/\left(2^{b\left(\gamma_{eff},s,z\right)+1}-2\right)}\right)\right]$$

$$W(s,z,K)=\left[\frac{\Gamma(K+s+sz)}{\Gamma(K+s+0.5\cdot sz)\Gamma(0.5\cdot sz+1)}\right]^{-1/(0.5\cdot sz+1)}$$

$$\text{wherein } \omega(b)=\frac{4}{2b+3},$$

$$\Gamma(x)=(x-1)!,$$

s represents a number of discrete-multi-tone symbols in a frame, z represents a

number of control code symbols per discrete-multi-tone symbol, b represents a

number of bit positions of a quadrature-amplitude-modulation symbol, $\omega(b)$

represents an average fraction of erroneous bits in an erroneous b-sized

quadrature-amplitude-modulation symbol, γ_{eff} represents an effective signal-to-noise

ratio; and

21   selecting the maximum number of symbol errors that can be corrected t, and

22   the number of symbols in the information field K such that the uncoded bit error rate

23   p_b that produces a symbol error rate that is less than or equal to the target symbol

24   error rate is increased.

1   2.   The method of claim 1 wherein the effective signal-to-noise ratio γ_{eff} is an

2   average signal-to-noise ratio of at least a subset of the channels.

1   3.   The method of claim 1 wherein the size of the frame ranges from 0 to

2        $N_{max}\text{-}s\text{-}zs$ symbols.

1   4.   The method of claim 1 further comprising:

2   determining a difference Θ between a bit error rate prior to decoding and the

3   target bit error rate (p_e) in accordance with the following relationship:

4

5
$$\Theta(K) = \omega\big(b(\gamma_{eff}, s, z)\big) p_{QAM} - p_e, \text{ and}$$

6

$$\omega\big(b(\gamma_{eff}, s, z)\big) p_{QAM}$$

7
$$= \omega\left[\frac{\alpha}{sn_{eff}}(K+s+zs)\left(1-2^{-\frac{\alpha}{2sn_{eff}}(K+s+zs)}\right)erfc\left(\sqrt{3\cdot 10^{\gamma_{eff}/10}\Big/\left(2^{\frac{\alpha}{sn_{eff}}(K+s+zs)+1}-2\right)}\right)\right.$$
$$\left.\times\left[2-\left(1-2^{-\frac{\alpha}{2sn_{eff}}(K+s+zs)}\right)erfc\left(\sqrt{3\cdot 10^{\gamma_{eff}/10}\Big/\left(2^{\frac{\alpha}{sn_{eff}}(K+s+zs)+1}-2\right)}\right)\right]\right]$$

8

9   wherein p_{QAM} represents a probability of error in transmitting a

10   quadrature-amplitude-modulation waveform representing a 2^b point constellation, and

11   p_e represents a channel symbol error rate; and

12   comparing the value of $\Theta(0)$ and $\Theta(N_{max}\text{-}s\text{-}zs)$ to 0; and

13   setting the value of K to a predetermined value in response to the comparing.

1   5.   The method of claim 4 wherein when $\Theta(0)<0$ and $\Theta(N_{max}\text{-}s\text{-}sz)<0$, setting

2    $K=N_{max}\text{-}s\text{-}zs$.

1   6.   The method of claim 1 further comprising setting $b(\gamma_{eff}, s, z)$ equal to

2

3    $$\frac{\alpha \; N_{max}}{s \; n_{eff}} \; .$$

1   7.   The method of claim 1 wherein when $\Theta(0)>0$ and $\Theta(N_{max}\text{-}s\text{-}sz)>0$, setting

2    $K=N_{max}\text{-}1$.

1   8.   The method of claim 7 further comprising setting $b(\gamma_{eff}, s, z)$ equal to

2    $b(\gamma_{eff}, 1, 0)$.

1   9.   A method of selecting forward error correction parameters in a channel having

2   a plurality of subchannels in a multicarrier communications system, comprising:

3   determining a signal-to-noise ratio representing a subset of the subchannels to

4   provide said representative performance measurement;

5   storing, in a table, the number (s) of discrete multi-tone symbols in a

6   forward-error-correction frame, the number (z) of forward-error-correction control

7   symbols in the discrete multitone symbol associated with the signal-to-noise ratio,

8   and the number of subchannels associated with the signal-to-noise ratio, and a net

9   coding gain for different values of s, z, signal-to-noise ratios and numbers of

10   subchannels; and

11 selecting forward error correction parameters of the channel based on the net

12 coding gain by applying an approximation to a subset of values in the table.

1 10. The method of claim 9 wherein the approximation is a bilinear approximation.

1 11. A method of selecting forward error correction parameters in a channel having

2 a plurality of subchannels in a multicarrier communications system, comprising:

3   determining a signal-to-noise ratio representing a subset of the subchannels to

4 provide said representative performance measurement;

5   storing, in a table, the number (s) of discrete multi-tone symbols in a

6 forward-error-correction frame, the number (z) of forward-error-correction control

7 symbols in the discrete multitone symbol associated with the signal-to-noise ratio, the

8 maximum number of transmissions (k) and the number of subchannels associated

9 with the signal-to-noise ratio, and a net coding gain for different values of s, z,

10 signal-to-noise ratios and numbers of subchannels; and

11   selecting forward error correction parameters of the channel based on the net

12 coding gain by applying an approximation to a subset of values in the table.

1 12. The method of claim 11 wherein the approximation is a bilinear

2 approximation.

1 13. The method of claim 11 wherein and the values of s and z are in accordance

2 with the G.dmt standard.

1 14. The method of claim 13 wherein the values of s and z are in accordance with

2 the G.lite standard, such that a subset of the tables associated with the values of s and

3 z in accordance with the G.dmt standard are used when the channel uses the G.lite

4 standard.

1   15.   A method of increasing a bit load of a multicarrier system comprising a

2   channel having a plurality of subchannels, comprising:

3   determining a bit load for at least one subchannel based on a target symbol error

4   rate ε_s, a maximum number of symbol errors that can be corrected t, a number of symbols

5   in an information field K, and a maximum number of transmissions k, and a number of

6   bits per subchannel; and

7   selecting the maximum number of symbol errors t, the number of symbols in the

8   information field K and the maximum number of transmissions k, such that a net coding

9   gain is increased, and wherein t, K and k are also selected such that no forward error

10   correction is applied when the number of subchannels exceeds a predetermined threshold

11   number of subchannels.

1   16.   The method of claim 15 wherein the channel uses the G.dmt standard.

1   17.   The method of claim 15 wherein the channel uses the G.lite standard.

1   18.   A method of determining an optimum bit load per subchannel in a multicarrier

2   system with forward error correction, comprising:

3   computing one or more values of a maximum number of symbol errors that

4   can be corrected t, and a number of symbols in the information field K to determine

5   the optimum bit load per subchannel in accordance with the following relationship:

6

$$1 - \left(1 - W(s,z,K)\varepsilon_S^{\frac{1}{0.5 \cdot sz+1}}\right)^{1/\alpha}$$

7

$$= \omega\left(b\left(\gamma_{eff},s,z\right)\right)\left(1 - 2^{-b(\gamma_{eff},s,z)/2}\right)erfc\left(\sqrt{3 \cdot 10^{\gamma_{eff}/10} /\left(2^{b(\gamma_{eff},s,z)+1} - 2\right)}\right), \text{ and}$$

$$\times\left[2 - \left(1 - 2^{-b(\gamma_{eff},s,z)/2}\right)erfc\left(\sqrt{3 \cdot 10^{\gamma_{eff}/10} /\left(2^{b(\gamma_{eff},s,z)+1} - 2\right)}\right)\right]$$

8

9
$$W(s,z,K) = \left[\frac{\Gamma(K+\rho s+sz)}{\Gamma(K+\rho s+0.5\cdot sz)\Gamma(0.5\cdot sz+1)}\right]^{-1/(0.5\cdot sz+1)}$$

10

11
$$\text{wherein } \omega(b) = \frac{4}{2b+3},$$

12

13
$$\Gamma(x)=(x-1)!,$$

14

15   s represents a number of discrete-multi-tone symbols in a frame, z represents a

16   number of control code symbols per discrete-multi-tone symbol, b represents a

17   number of bit positions of a quadrature-amplitude-modulation symbol, $\omega(b)$

18   represents an average fraction of erroneous bits in an erroneous b-sized

19   quadrature-amplitude-modulation symbol, γ_{eff} represents an effective signal-to-noise

20   ratio, and ρ represents a number of overhead symbols per discrete multi-tone symbol;

21   and

22   selecting the maximum number of symbol errors that can be corrected t, and

23   the number of symbols in the information field K such that the uncoded bit error rate

24   p_b that produces a symbol error rate that is less than or equal to the target symbol

25   error rate is increased.

1   19.   The method of claim 18 wherein the effective signal-to-noise ratio γ_{eff} is an

2   average signal-to-noise ratio of at least a subset of the channels.

1   20.   The method of claim 18 wherein the size of the frame ranges from 0 to

2   N_{max}-ρs-sz symbols.

1   21.   The method of claim 18 further comprising:

2   determining a difference Θ between a bit error rate prior to decoding and the

3   target bit error rate (p_e) in accordance with the following relationship:

4

5

$$\Theta(K) = \omega\big(b\big(\gamma_{eff}, s, z\big)\big)p_{QAM} - p_e, \text{ and}$$

6

7

$$\omega\big(b\big(\gamma_{eff}, s, z\big)\big)p_{QAM}$$

$$= \omega\left[\frac{\alpha}{sn_{eff}}(K + \rho s + zs)\left(1 - 2^{-\frac{\alpha}{2sn_{eff}}(K+\rho s+zs)}\right)erfc\left(\sqrt{3\cdot 10^{\gamma_{eff}/10} / \left(2^{\frac{\alpha}{sn_{eff}}(K+\rho s+zs)+1} - 2\right)}\right)\right.$$

$$\left. \times\left[2 - \left(1 - 2^{-\frac{\alpha}{2sn_{eff}}(K+\rho s+zs)}\right)erfc\left(\sqrt{3\cdot 10^{\gamma_{eff}/10} / \left(2^{\frac{\alpha}{sn_{eff}}(K+\rho s+zs)+1} - 2\right)}\right)\right]\right]$$

8

9   wherein p_{QAM} represents a probability of error in transmitting a

10   quadrature-amplitude-modulation waveform representing a 2^b point constellation, and

11   p_e represents a channel symbol error rate; and

12   comparing the value of $\Theta(0)$ and $\Theta(N_{max}-\rho s-sz)$ to 0; and

13   setting the value of K to a predetermined value in response to the comparing.

1   22.   The method of claim 18 wherein when $\Theta(0)<0$ and $\Theta(N_{max}-\rho s-sz)<0$, setting

2   $K=N_{max}-\rho s-sz$.

1   23.   The method of claim 22 further comprising setting $b(\gamma_{eff}, s, z)$ equal to

2

3   $$\frac{\alpha\ N_{max}}{s\ n_{eff}} \ .$$

1   24.   The method of claim 18 wherein when $\Theta(0)>0$ and $\Theta(N_{max}-\rho s-sz)>0$, setting

2    $K=N_{max}-\rho$.

1   25.   The method of claim 24 further comprising setting $b(\gamma_{eff}, s, z)$ equal to

2    $b(\gamma_{eff}, 1, 0)$.

1   26.   An apparatus for determining an optimum bit load per subchannel in a

2   multicarrier system with forward error correction, comprising:

3   means for computing one or more values of a maximum number of symbol

4   errors that can be corrected t, and a number of symbols in the information field K to

5   determine the optimum bit load per subchannel in accordance with the following

6   relationship:

7

8

$$1-\left(1-W(s,z,K)\varepsilon_S^{\frac{1}{0.5\cdot sz+1}}\right)^{1/\alpha}$$

$$=\omega\left(b\left(\gamma_{eff},s,z\right)\right)\left(1-2^{-b\left(\gamma_{eff},s,z\right)/2}\right)erfc\left(\sqrt{3\cdot 10^{\gamma_{eff}/10}/\left(2^{b\left(\gamma_{eff},s,z\right)+1}-2\right)}\right), \text{ and}$$

$$\times\left[2-\left(1-2^{-b\left(\gamma_{eff},s,z\right)/2}\right)erfc\left(\sqrt{3\cdot 10^{\gamma_{eff}/10}/\left(2^{b\left(\gamma_{eff},s,z\right)+1}-2\right)}\right)\right]$$

9

10

$$W(s,z,K)=\left[\frac{\Gamma(K+s+sz)}{\Gamma(K+s+0.5\cdot sz)\Gamma(0.5\cdot sz+1)}\right]^{-1/(0.5\,sz+1)}$$

11

12

$$\text{wherein } \omega(b)=\frac{4}{2b+3},$$

13

14

$$\Gamma(x)=(x-1)!,$$

15

16 s represents a number of discrete-multi-tone symbols in a frame, z represents a

17 number of control code symbols per discrete-multi-tone symbol, *b* represents a

18 number of bit positions of a quadrature-amplitude-modulation symbol, $\omega(b)$

19 represents an average fraction of erroneous bits in an erroneous *b*-sized

20 quadrature-amplitude-modulation symbol, γ_{eff} represents an effective signal-to-noise

21 ratio; and

22   means for selecting the maximum number of symbol errors that can be

23 corrected t, and the number of symbols in the information field K such that the

24 uncoded bit error rate p_b that produces a symbol error rate that is less than or equal to

25 the target symbol error rate is increased.

1   27.   The apparatus of claim 26 wherein the effective signal-to-noise ratio γ_{eff} is an

2   average signal-to-noise ratio of at least a subset of the channels.

1   28.   The apparatus of claim 22 wherein the size of the frame ranges from 0 to

2   N_{max}-s-zs symbols.

1   29.   The apparatus of claim 26 further comprising:

2   means for determining a difference Θ between a bit error rate prior to

3   decoding and the target bit error rate (p_e) in accordance with the following

4   relationship:

5

6   $$\Theta(K) = \omega\big(b\big(\gamma_{eff}, s, z\big)\big) p_{QAM} - p_e, \text{ and}$$

7

$$\omega\big(b(\gamma_{eff},s,z)\big)p_{QAM}$$

8
$$= \omega\left(\frac{\alpha}{sn_{eff}}(K+s+zs)\right)\left(1-2^{-\frac{\alpha}{2sn_{eff}}(K+s+zs)}\right)erfc\left(\sqrt{3\cdot10^{\gamma_{eff}/10}\left/\left(2^{\frac{\alpha}{sn_{eff}}(K+s+zs)+1}-2\right)\right.}\right)$$

$$\times\left[2-\left(1-2^{-\frac{\alpha}{2sn_{eff}}(K+s+zs)}\right)erfc\left(\sqrt{3\cdot10^{\gamma_{eff}/10}\left/\left(2^{\frac{\alpha}{sn_{eff}}(K+s+zs)+1}-2\right)\right.}\right)\right]$$

9

10 wherein p_{QAM} represents a probability of error in transmitting a

11 quadrature-amplitude-modulation waveform representing a 2^b point constellation, and

12 p_e represents a channel symbol error rate; and

13   means for comparing the value of $\Theta(0)$ and $\Theta(N_{max}\text{-}s\text{-}zs)$ to 0; and

14   means for setting the value of K to a predetermined value in response to the

15 comparing.

1   30.   The apparatus of claim 26 wherein when $\Theta(0)<0$ and $\Theta(N_{max}\text{-}s\text{-}sz)<0$, setting

2 $K=N_{max}\text{-}s\text{-}zs.$

1   31.   The apparatus of claim 30 further comprising setting $b(\gamma_{eff},\,s,\,z)$equal to

2

3    $\dfrac{\alpha\ N_{max}}{s\ n_{eff}}$.

1   32.   The apparatus of claim 30 wherein when $\Theta(0)>0$ and $\Theta(N_{max}\text{-}s\text{-}sz)>0$, setting

2 $K=N_{max}\text{-}1.$

1   33.   The apparatus of claim 32 further comprising setting $b(\gamma_{eff},\,s,\,z)$equal to

2 $b(\gamma_{eff},\,1,\,0).$

1   34.   An apparatus for selecting forward error correction parameters in a channel

2   having a plurality of subchannels in a multicarrier communications system,

3   comprising:

4   means for determining a signal-to-noise ratio representing a subset of the

5   subchannels to provide said representative performance measurement;

6   means for storing, in a table, the number (s) of discrete multi-tone symbols in

7   a forward-error-correction frame, the number (z) of forward-error-correction control

8   symbols in the discrete multitone symbol associated with the signal-to-noise ratio,

9   and the number of subchannels associated with the signal-to-noise ratio, and a net

10   coding gain for different values of s, z, signal-to-noise ratios and numbers of

11   subchannels; and

12   means for selecting forward error correction parameters of the channel based

13   on the net coding gain by applying an approximation to a subset of values in the table.

1   35.   The apparatus of claim 34 wherein the approximation is a bilinear

2   approximation.

1   36.   An apparatus for selecting forward error correction parameters in a channel

2   having a plurality of subchannels in a multicarrier communications system,

3   comprising:

4   means for determining a signal-to-noise ratio representing a subset of the

5   subchannels to provide said representative performance measurement;

6   means for storing, in a table, the number (s) of discrete multi-tone symbols in

7   a forward-error-correction frame, the number (z) of forward-error-correction control

8   symbols in the discrete multitone symbol associated with the signal-to-noise ratio, the

9   maximum number of transmissions (k) and the number of subchannels associated

10   with the signal-to-noise ratio, and a net coding gain for different values of s, z,

11   signal-to-noise ratios and numbers of subchannels; and

12   means for selecting forward error correction parameters of the channel based

13   on the net coding gain by applying an approximation to a subset of values in the table.

1   37.   The apparatus of claim 36 wherein the approximation is a bilinear

2   approximation.

1   38.   The apparatus of claim 36 wherein the values of s and z are in accordance

2   with the G.dmt standard.

1   39.   The apparatus of claim 38 wherein the values of s and z are in accordance

2   with the G.lite standard, such that a subset of the tables associated with the values of s

3   and z in accordance with the G.dmt standard are used when the channel uses the

4   G.lite standard.

1   40.   An apparatus for increasing a bit load of a multicarrier system comprising a

2   channel having a plurality of subchannels, comprising:

3   means for determining a bit load for at least one subchannel based on a target

4   symbol error rate ε_s, a maximum number of symbol errors that can be corrected t, a

5   number of symbols in an information field K, and a maximum number of transmissions k,

6   and a number of bits per subchannel; and

7   means for selecting the maximum number of symbol errors t, the number of

8   symbols in the information field K and the maximum number of transmissions k, such

9   that a net coding gain is increased wherein the means for also selects t, K and k such that

10   no forward error correction is applied when the number of subchannels exceeds a

11   predetermined threshold number of subchannels.

1   41.   An apparatus for determining an optimum bit load per subchannel in a

2   multicarrier system with forward error correction, comprising:

3   means for computing one or more values of a maximum number of symbol

4   errors that can be corrected t, and a number of symbols in the information field K to

5   determine the optimum bit load per subchannel in accordance with the following

6   relationship:

7

8

$$1 - \left(1 - W(s,z,K)\varepsilon_s^{\frac{1}{0.5 \cdot sz+1}}\right)^{1/\alpha}$$

$$= \omega\big(b(\gamma_{eff},s,z)\big)\Big(1 - 2^{-b(\gamma_{eff},s,z)/2}\Big)erfc\left(\sqrt{3 \cdot 10^{\gamma_{eff}/10}/\big(2^{b(\gamma_{eff},s,z)+1}-2\big)}\right), \text{ and }$$

$$\times\left[2 - \Big(1 - 2^{-b(\gamma_{eff},s,z)/2}\Big)erfc\left(\sqrt{3 \cdot 10^{\gamma_{eff}/10}/\big(2^{b(\gamma_{eff},s,z)+1}-2\big)}\right)\right]$$

9

10

$$W(s,z,K) = \left[\frac{\Gamma(K+\rho s+sz)}{\Gamma(K+\rho s+0.5 \cdot sz)\Gamma(0.5 \cdot sz+1)}\right]^{-1/(0.5 sz+1)}$$

11

12

$$\text{wherein } \omega(b) = \frac{4}{2b+3},$$

13

14

$$\Gamma(x) = (x-1)!,$$

15

16   s represents a number of discrete-multi-tone symbols in a frame, z represents a

17   number of control code symbols per discrete-multi-tone symbol, b represents a

18   number of bit positions of a quadrature-amplitude-modulation symbol, $\omega(b)$

19   represents an average fraction of erroneous bits in an erroneous b-sized

20   quadrature-amplitude-modulation symbol, γ_{eff} represents an effective signal-to-noise

21   ratio, and ρ represents a number of overhead symbols per discrete multi-tone symbol;

22   and

23   means for selecting the maximum number of symbol errors that can be

24   corrected t, and the number of symbols in the information field K such that the

25   uncoded bit error rate p_b that produces a symbol error rate that is less than or equal to

26   the target symbol error rate is increased.

1   42.   The apparatus of claim 41 wherein the effective signal-to-noise ratio γ_{eff} is an

2   average signal-to-noise ratio of at least a subset of the channels.

1   43.   The apparatus of claim 41 wherein the size of the frame ranges from 0 to

2   N_{max}-ρs-sz symbols.

1   44.   The apparatus of claim 41 further comprising:

2   means for determining a difference Θ between a bit error rate prior to

3   decoding and the target bit error rate (p_e) in accordance with the following

4   relationship:

5

6    $$\Theta(K) = \omega\left(b\left(\gamma_{eff}, s, z\right)\right) p_{QAM} - p_e,$$

7

$$\omega\left(b\left(\gamma_{eff}, s, z\right)\right) p_{QAM}$$

8    $$= \omega\left[\frac{\alpha}{sn_{eff}}(K + \rho s + zs)\left(1 - 2^{-\frac{\alpha}{2sn_{eff}}(K+\rho s+zs)}\right) erfc\left(\sqrt{3 \cdot 10^{\gamma_{eff}/10} / \left(2^{\frac{\alpha}{sn_{eff}}(K+\rho s+zs)+1} - 2\right)}\right)\right.$$

$$\left. \times \left[2 - \left(1 - 2^{-\frac{\alpha}{2sn_{eff}}(K+\rho s+zs)}\right) erfc\left(\sqrt{3 \cdot 10^{\gamma_{eff}/10} / \left(2^{\frac{\alpha}{sn_{eff}}(K+\rho s+zs)+1} - 2\right)}\right)\right]\right]$$

9

10   wherein p_{QAM} represents a probability of error in transmitting a

11   quadrature-amplitude-modulation waveform representing a 2^b point constellation, and

12   p_e represents a channel symbol error rate;

13   comparing the value of $\Theta(0)$ and $\Theta(N_{max}-\rho s-zs)$ to 0; and

14   setting the value of K to a predetermined value in response to the comparing.

1   45.   The apparatus of claim 41 wherein when $\Theta(0)<0$ and $\Theta(N_{max}-\rho s-sz)<0$,

2   setting $K=N_{max}-\rho s-zs$.

1   46.   The apparatus of claim 45 further comprising setting $b(\gamma_{eff}, s, z)$ equal to

2

3     $$\frac{\alpha \; N_{max}}{s \; n_{eff}} \; .$$

1   47.   The apparatus of claim 41 wherein when $\Theta(0)>0$ and $\Theta(N_{max}-\rho s-sz)>0$,

2   setting $K=N_{max}-\rho$.

1   48.   The apparatus of claim 47 further comprising setting $b(\gamma_{eff}, s, z)$ equal to

2     $b(\gamma_{eff}, 1, 0)$.